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"On the Liquation, Fusibility, and Density of certain Alloys of Silver and Copper." By W. Chandler Roberts, Chemist of the Mint. Communicated by Dr. Percy, F.R.S. Received March 11, 1875*.

Alloys of silver and copper possess many curious chemical and physical properties which make them interesting apart from their economic value, and entitle them to careful investigation. The most remarkable of these is a molecular mobility, in virtue of which certain combinations of the constituents of a molten alloy become segregated from the mass, the homogeneous character of which is thereby destroyed.

These irregularities of composition have long been known. Some observations of Lazarus Erckern, in a work published in the seventeenth century†, show that he was familiar with them; that Jars possessed more accurate information on the subject is proved by his stating explicitly, in a memoir published in 1781‡, that in ingots of silver-copper alloys containing much of the base metal, the centre of the mass is less rich than the external portions.

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* Read March 18, 1875. See *antè*, p. 349.

† His work was translated in 1686 by Sir John Pettus. See 'Fleta Minor,' Book I. p. 62.

‡ Voyages Métallurgiques, t. iii. p. 270.

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The alloys in question have, during the present century, been the subject of many excellent researches in this country and on the continent, the earliest systematic experiments being those of D'Arcet, Inspecteur Général des Essais at the French Mint, who in 1824 investigated the phenomena which attend the cooling of molten mixtures of silver and copper. He does not appear to have published his results; but in 1852 Levol stated, in a well-known memoir*, that the object D'Arcet had in view was the discovery of a method of rendering homogeneous the bars of metal used in coinage. He adds that the researches in this direction offered little prospect of obtaining such a result. I shall presently show, as the result of my experiments, that this conclusion may now be modified.

Levol, in his own experiments, cast the alloy to be examined either in a cubical iron mould of 45 millims. side, or in a sphere 50 millims. in diameter. He concluded that the only homogeneous alloy contains 718·93 parts of silver and 281·07 of copper in 1000; and he considers this to be a definite combination of the two metals, having the formula $Ag_3 Cu_4$ (or $Ag_3 Cu_2$ if 63·34 be taken to be the equivalent of copper). All other alloys of silver and copper he views as mixtures of this definite alloy with excess of either of the metals.

In 1860† Matthiessen studied these alloys with the minute accuracy which characterized all his work, and he described them as "mechanical mixtures of allotropic modifications of the two metals in each other." The curve of electric conductivity led him to doubt Levol's conclusion that they were mixtures of the definite alloy $Ag_3 Cu_2$ (new notation) with silver or copper; for, as he observes, if this were the case, we should expect to find that the curve consisted of two straight lines, connecting Levol's alloy with pure silver and copper respectively. But on examining the curve, starting from the copper side of it, we see that a rapid decrement in conducting-power is caused by copper being alloyed with a small quantity of silver. From the alloy containing 10 per cent. of silver to that containing 65 per cent. we have a straight line; and we may regard the intermediate alloys as mixtures or solutions of these two alloys. Again, from the latter of these to that containing 72 per cent. of silver, we may have a mixture or solution of alloys containing 65 and 72 per cent. respectively. This last point (which corresponds to a conducting-power of 63·7, fine silver being taken as 100) is the minimum point of the curve, and corresponds almost exactly to Levol's $Ag_3 Cu_2$ alloy. The alloys intermediate between this and pure silver may be mixtures, or perhaps solutions of it in silver containing a small quantity of copper. Now it would appear as if there was an alloy of constant composition at about the point which represents the one containing 65 per cent.

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* "Sur les alliages considérés sous le rapport de leur composition chimique," Ann. Chim. et Phys. (3) t. xxxvi.

† Phil. Trans. 1860, p. 173.

of silver; otherwise we should expect a straight line from the alloy containing 72 per cent. of silver to that which contains only 10 per cent.

I now proceed to give the results of my own experiments.

In commencing the inquiry, it seemed probable that, by determining the melting-points of a series of the alloys of silver and copper, information of much interest might be gained as to the arrangement which attends the solidification of a fluid mass of these metals. I adopted a modification of the plan described by Pouillet*, and employed by him in determining the specific heat of platinum at high temperatures.

As soon as the alloy under examination was melted, a wrought-iron cylinder of known weight was dropped into it by means of a wire support. The crucible was then removed from the furnace, and, when the alloy showed signs of solidifying, the iron was transferred to a calorimeter, which consisted of two concentric vessels of thin polished brass, such as is ordinarily used for determining specific heats by the method of mixtures.

It was necessary to determine the mean specific heat of the iron employed, between 0° C. and a known fixed point near the maximum temperature likely to be attained in the course of the experiments. The melting-point of silver was a convenient one, and it has been accurately ascertained by M. Becquerel†, who placed a wire of pure silver in a crucible which was enclosed in a porcelain tube surrounded by the vapour of boiling zinc, the temperature of which has been fixed by M. Deville at 1040° C.‡ As the heat was sufficient to partially fuse the silver, this temperature may safely be taken as the melting-point of the metal.

In order, therefore, to determine the specific heat of the iron, I plunged the cylinder into molten silver, and transferred it to the calorimeter. I may here observe that the film of oxide which formed on the surface of the iron to a great extent protected it from being attacked by the molten alloy; but it was impossible to avoid carrying into the calorimeter a small quantity of metal which adhered to the iron. The metal so introduced was always collected and allowed for. With pure silver 0·05701 was taken as the specific heat, while in the case of alloys the necessary correction was made by deducing the specific heat of each alloy from the specific heats of its constituents; and the equivalent weight of iron was calculated by multiplying the weight of introduced metal by its specific heat, and dividing this product by the specific heat of iron as ascertained by preliminary experiments. This weight was then added to that of the iron employed.

The specific heats of metals at high temperatures have not been determined, and the adoption of Regnault's numbers in calculating the heat carried into the calorimeter by the alloys may tend to make the results a few degrees too high.

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* Éléments de Physique, sixième édition, t. ii. p. 564.

† Ann. Chim. et Phys. (3) t. lxviii. p. 74.

‡ Comptes Rendus, t. lvii. p. 897.

The results of the experiments were calculated by means of the following formula :—

$$x=\frac{(P+p_{,}c_{,}+p_{,,}c_{,,})(\Theta-t)}{p(T-\Theta)},$$

where p is the weight of the iron employed.

P „ „ water.

$p_{,}c_{,}$ and $p_{,,}c_{,,}$ are the water-equivalents of the calorimeter and thermometer respectively.

T is the initial temperature of the iron.

t „ „ „ „ water.

Θ „ final „

x „ specific heat required.

In one experiment these quantities had the following values :—

$p = 83{\cdot}140$ grms. $T = 1040°$ C.

$P = 260{\cdot}520$ „ $t = 16°$ C.

$p_{,}c_{,}+p_{,,}c_{,,} = 15{\cdot}687$ „ $\Theta = 63°$ C.

The weight of silver carried over was 3·266 grms., the heating effect of which is equivalent to that of 1·306 grm. of iron. Therefore the corrected value of p is $83{\cdot}140+1{\cdot}306=84{\cdot}446$ grms.

Substituting these values in the above equation,

$$x=\frac{(260{\cdot}52+15{\cdot}687)(63-16)}{84{\cdot}446\,(1040-63)}$$
$$={\cdot}15734.$$

Three successive experiments gave

·15795,
·15550,
·15734,
the mean ·15693 being finally adopted[*]

It may be pointed out that the specific heat of iron as thus determined includes and neutralizes several errors which are incidental to this method of determining high temperatures. The principal of these are :—(1) the loss of heat, which is rendered latent by the small amount of water which is evaporated; (2) the slight difference between the specific heat of the iron and the specific heat of the oxide formed on its surface; (3) the loss of heat sustained by the iron during its transfer from the crucible to the calorimeter; and (4) the radiation from this instrument.

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[*] Weinhold gives 0·1567 as the mean specific heat of wrought iron between 0° and 900° C. (Pogg. Ann. vol. cxlix. p. 214).

The melting-point of copper has not been exactly ascertained; and I experienced great difficulty in determining it by means of the calorimeter, as the molten metal adheres tenaciously to the iron. Accuracy on this point is not absolutely essential to this inquiry, and I therefore adopted 1330° C., as this is considered by Dr. Van Riemsdijk* to be the probable melting-point of pure copper.

The several alloys were synthetically prepared by melting together pure silver and pure copper; and as soon as the crucible containing the fused metal was withdrawn from the furnace, a small portion of the thoroughly stirred alloy was granulated and set aside for analysis.

The requisite data for ascertaining the melting-point of each alloy were furnished by an experiment similar to that which was made for determining the specific heat of the iron, and in calculating the result it was only necessary to transpose the equation already given, T being the unknown quantity instead of x. The formula then becomes

$$T=\frac{(P+p_{,}c_{,}+p_{,,}c_{,,})(\Theta-t)}{p\,x}+\Theta,$$

the value assigned to x being in all cases 0·15693, the mean specific heat of iron, as given above.

To take an example. In one experiment to determine the melting-point of the 820·7 alloy, the following values were obtained:—

$P = 247{\cdot}74$ grms. $t = 15°$ C.
$p_{,}c_{,}+p_{,,}c_{,,} = 15{\cdot}687$ " $\Theta = 56°$ C.
$p = 82{\cdot}55$ "

The weight of alloy carried over was 3·608 grms., the heating effect of which was equivalent to that of 1·543 grm. of iron. Therefore the corrected value of p is

$$82{\cdot}55 + 1{\cdot}543 \text{ grm.} = 84{\cdot}093 \text{ grms.}$$

Substituting these values in the above equation,

$$T=\frac{(247{\cdot}74+15{\cdot}687)(56-15)}{84{\cdot}093\times{\cdot}15693}+56$$
$$=874^{\circ}{\cdot}42 \text{ C.}$$

The results of the experiments are given in the following Table:—

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* Archives Néerlandaises, t. iii. (1868).

Melting-points of Silver-Copper Alloys.

No.	Parts of pure silver in 1000 parts of the alloy.	Approximate formula.	Melting-points, in degrees Centigrade.	
			Observed.	Mean.
1.	1000 (pure silver).	...	...	1040
2.	925	$Ag_7 Cu$	919·9 939·0 934·5	931·1
3.	820·7	$Ag_3 Cu$	874·6 891·8 900·5 877·8	886·2
4.*	798	$Ag_5 Cu_2$	882·4 885·4 889·5 890·9	887·0
5.*	773·6	$Ag_2 Cu$	854·9 857·9 862·3	858·3
6.*	750·3	$Ag_7 Cu_4$	852·3 848·5	850·4
7.	718·93	$Ag_3 Cu_2$	868·4 863·5 879·5	870·5
8.	630·29	$Ag Cu$	851·9 844·9 837·6 852·7	846·8
9.	600	$Ag_7 Cu_8$	854·9 849·8 858·6 864·6	857·0
10.*	569·6	$Ag_7 Cu_9$	897·6 902·2	899·9
11.*	561·1	$Ag_3 Cu_4$	910·8 914·8 927·2	917·6
12.*	540·8	$Ag_{20} Cu_{29}$	914·1 916·0 921·5 927·6	919·8
13.*	500	$Ag_3 Cu_5$	931·9 944·1 945·6	940·8

Melting-points of Silver-Copper Alloys (*continued*).

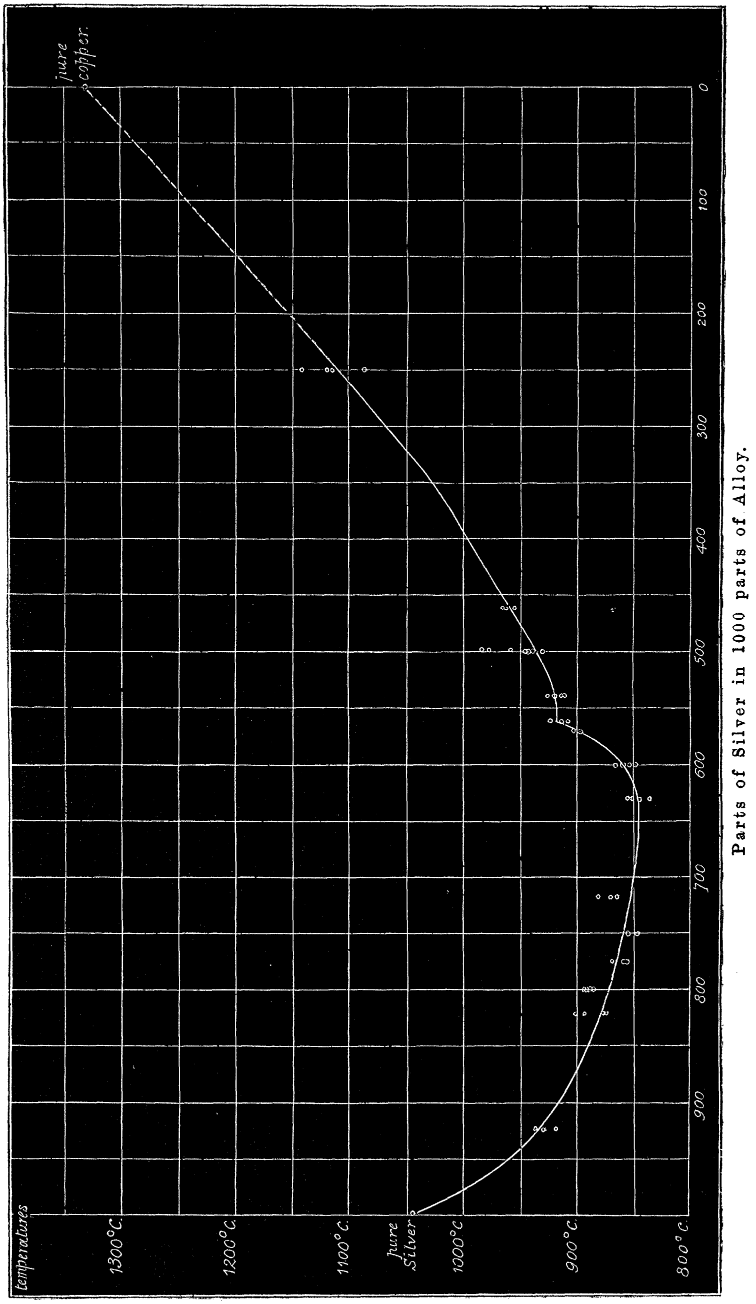
No.	Parts of pure silver in 1000 parts of the alloy.	Approximate formula.	Melting-points, in degrees Centigrade.	
			Observed.	Mean.
14.	497	$Ag_{15} Cu_{26}$	940·2 973·0 981·5 955·6	962·6
15.*	459·4	$Ag Cu_2$	953·5 963·9 964·1	960·8
16.	250·5	$Ag Cu_5$	1080·8 1141·8 1114·9 1119·1	1114·1
17.	0 (pure copper).	...	...	1330

These melting-points are graphically represented by the accompanying curve (next page); the coordinates are the amounts of silver in the several alloys and their melting-points.

It will be observed that the curve exhibits a somewhat rapid decrement from pure silver to the alloy which contains 925 parts of silver, the one employed for the British silver coins. In it the relation between the amounts of metals present is approximately represented by the formula $Ag_7 Cu$.

The alloys numbered 7 and 8 are of singular interest. The first, which contains 718·93 parts of silver, is Levol's homogeneous alloy; and I anticipated that it would have the lowest melting-point; but the results showed that the alloy containing 630·29 parts of silver (No. 8) melts at a point which is 23·7 degrees lower. In this alloy a very simple relation exists between the atoms of the constituent metals, the formula being $Ag Cu$. Additional interest is imparted to it by Matthiessen's curve of electric conductivity having shown that the arrangement of an alloy of this composition would probably be peculiar. From this point the curve passes through the points representing alloys in which base metal predominates to 1330° C., the melting-point of pure copper.

Further evidence as to the melting-points of Nos. 7 and 8 was afforded by placing strips of them in small covered crucibles surrounded by the vapour of boiling cadmium, the temperature of which has been fixed by Deville at 860° C. Both alloys melted, the first partially, the second completely. I am convinced, therefore, that the melting-points of the alloys generally are not inaccurately indicated by the curve. It is, however, not improbable that the examination of a more extended series of alloys may



MELTING-POINTS OF SILVER-COPPER ALLOYS.

point to the necessity of slightly modifying its form. This critical examination is especially necessary in the region of the 497 alloy; for not only do the results obtained on it diverge widely among themselves, but their mean is far removed from the probable line of the curve.

I am not satisfied with the results I have obtained on an alloy which contains 773·2 parts of silver. This alloy is of special interest; its formula is $Ag_2' Cu''$, silver being monatomic.

[Since the above was submitted to the Royal Society, I have made additional experiments on alloys in these two portions of the curve. The calorimeter used was of thin polished silver, capable of holding 1200 grammes of water, which were never raised through more than 15° C. The water-equivalent of the instrument was only 15·72 grammes. The masses of iron used were such as had been employed as carriers of heat in the first experiments: the mean of several very concordant results gave ·15003 as the specific heat of the iron when this new calorimeter is employed; and, as has already been pointed out (p. 484), this number includes and neutralizes several errors.

The results are distinguished by an asterisk in the Table, and have been added to those originally indicated in the Diagram. They confirm the direction originally given to the curve in the region of the alloys which contain from 718 to 800 parts of silver; but the existence of a cusp has been detected at the point which represents the alloy No. 11 ($Ag_3 Cu_4$). It may be interesting to point out that the results from which Matthiessen's curve of electric conductivity was developed appear to prove the presence of a cusp at the point which represents the alloy 459·4 ($Ag Cu_2$).—*15th May*, 1875.]

It may be useful to compare these results with those obtained by Rudberg on alloys of lead and tin. He found that when a thermometer is placed in a molten alloy of these metals two distinct stationary points are indicated during the passage from the liquid to the solid state. One of these points is always 187° C.; and in the alloy $Pb Sn_6$ the two points coincide at this temperature—a fact which led Rudberg to conclude that it was the only alloy in which the whole of the metals were chemically combined. I hope, in continuing this inquiry, to be able to ascertain whether the change of state in the case of silver-copper alloys also terminates at a constant temperature. I may mention that M. A. Rich* determined the melting-points of certain alloys of tin and copper by means of Becquerel's thermo-electric pyrometer; and he obtained concordant results with the alloys $Sn Cu_3$ and $Sn Cu_4$; but with all other alloys the results differed widely among themselves.

It is at present difficult to show the direct bearing of these results on the phenomena of liquation in alloys of silver and copper; but the curve is valuable, as it proves that the alloys Nos. 7 and 8 occupy positions in

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* Ann. Chim. et Phys. t. xxx. p. 351.

LIQUATION IN SILVER-

ALLOY CONTAINING { 925 SILVER.
75 COPPER.

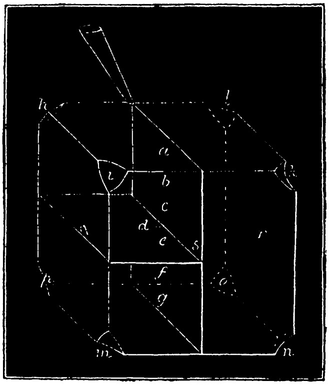


Fig. 1.

RAPIDLY COOLED.

Vertical Plane.	*a.*	924·6
	b.	926·0
	c.	929·1
	d.	935·5
	e.	931·0
	f.	925·0
	g.	924·2
Corners.	*h.*	923·2
	i.	923·7
	k.	923·3
	l.	923·3
Corners.	*m.*	923·9
	n.	923·8
	o.	922·7
	p.	923·2
Sides.	*q.*	923·6
	r.	923·8
	s.	923·1

"Dip assay," 925·1.

Maximum difference [between the centre and the corners], 12·8 per thousand.

ALLOY CONTAINING { 900 SILVER.
100 COPPER.

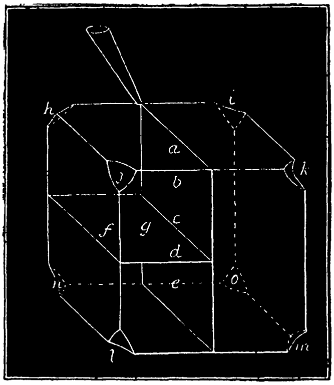


Fig. 3

SLOWLY COOLED.

Vertical Plane.	*a.*	899·0
	b.	899·2
	c.	899·6
	d.	898·6
	e.	899·1
Corners.	*h.*	898·9
	i.	898·6
	j.	899·4
	k.	898·3
Corners.	*l.*	899·6
	m.	899·5
	n.	899·3
	o.	898·8
Horizontal Plane.	*f.*	898·5
	g.	898·6

"Dip assay," 900·4.

Maximum difference, 1·3 per thousand.

ALLOY CONTAINING { 630·3 SILVER.
369·7 COPPER.

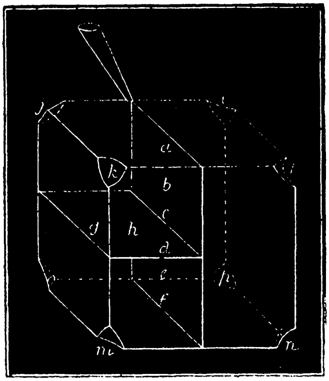


Fig. 5

SLOWLY COOLED.

Vertical Plane.	*a.*	614·9
	b.	631·5
	c.	636·0
	d.	635·0
	e.	630·9
	f.	634·8
Corners.	*i.*	620·6
	j.	620·3
	k.	625·9
	l.	625·0
Corners.	*m.*	632·6
	n.	633·5
	o.	633·9
	p.	634·
Horizontal Plane.	*g.*	631·4
	h.	635·9

"Dip assay," 630·2.

COPPER ALLOYS.

ALLOY CONTAINING {925 SILVER. 75 COPPER.

SLOWLY COOLED.

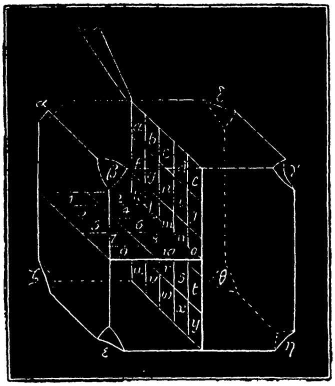


Fig. 2.

Vertical Plane.	*a.*	925·7
	b.	925·0
	c.	925·0
	d.	925·0
	e.	925·4
	f.	924·3
	g.	925·0
	h.	925·3
	i.	925·3
	j.	925·3
	k.	924·3
	l.	925·3
	m.	925·3
	n.	924·4
	o.	925·0
	p.	924·3
	q.	925·0
	r.	925·3
	s.	925·0
	t.	924·9
	u.	924·3
	v.	924·7
	w.	924·9
	x.	924·9
	y.	925·3

Horizontal Plane.	1.	924·8
	2.	925·0
	3.	924·9
	4.	924·9
	5.	925·0
	6.	925·1
	7.	925·1
	8.	925·1
	9.	925·0
	10.	925·0
Corners.	α.	924·1
	β.	924·1
	γ.	924·1
	δ.	924·4
	ε.	924·0
	ζ.	924·2
	η.	924·2
	θ.	923·9

"Dip assay," 924·9.

Maximum difference [between the centre and the corners], 1·40 per thousand.

ALLOY CONTAINING {718·93 SILVER. 281·07 COPPER.

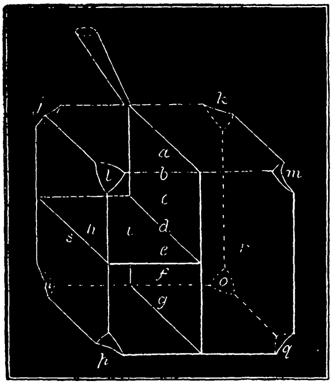


Fig. 4.

SLOWLY COOLED.

Vertical Plane.	*a.*	718·3
	b.	719 5
	c.	718·3
	d.	718·4
	e.	718·3
	f.	718·4
	g.	718·2
Sides.	*r.*	718·8
	s.	718·4

Horizontal Plane.	*h.*	718·7
	i.	718·5
Corners.	*j.*	719·0
	k.	719·0
	l.	719·0
	m.	719·4
	n.	719·1
	o.	719·0
	p.	719·0
	q.	719·1

"Dip assay," 719·0.

Maximum difference, 1·2 per thousand.

ALLOY CONTAINING {333·3 SILVER. 666·7 COPPER.

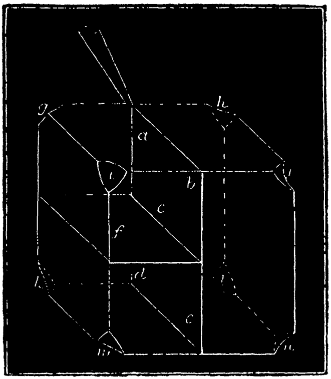


Fig. 6.

SLOWLY COOLED.

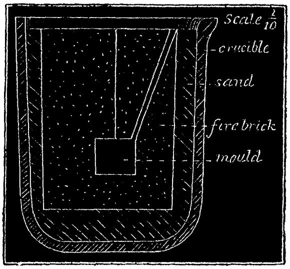
Vertical Plane.	*a.*	342·8
	b.	333·0
	c.	337·5
	d.	330·0
	e.	332·0
Corners.	*g.*	331·0
	h.	332·0
	i.	331·5
	j.	334·8

Corners.	*k.*	331·0
	l.	334·0
	m.	336·3
	n.	334·4
Horizontal Plane.	*f.*	336·2

"Dip assay," 333·4.

the lower portions of the curve similar to those which they hold on Matthiessen's curve of electric conductivity.

Fig. 7.



The range of temperature which these melting-points exhibit appears to justify the conclusion that liquation is in some way the result of the unequal cooling of a mass of silver and copper, and that if the cooling could be greatly protracted the liquation would be considerably modified. In order to ascertain whether this were the case, I used cubical moulds (about 45 millims. side) of firebrick (fig. 7), which were easily heated to bright redness, and in which the alloys could be *slowly* and *uniformly* cooled*.

All the cubes represented on pp. 490 & 491 were cast in moulds of this description. The first of these (fig. 1), the composition of which was about 925 parts of silver per 1000 of the alloy, was cooled rapidly. Its structure confirms Levol's general conclusion, as the centre contains 12·8 parts per thousand more silver than the external portions. On the other hand, fig. 2 shows that when the same alloy is slowly cooled the constituents hardly undergo any molecular re-arrangement, the maximum difference being only 1·4 per thousand. A cube of the alloy used for the French coinage, when rapidly cooled, exhibits a difference of 10·1 parts per thousand between the centre and the corners; but when the same metal is slowly cooled (fig. 3), the variation is only 1·3 parts per thousand. The maximum difference found by Levol in his homogeneous alloy was 0·44 part per thousand. I find (fig. 4) that if the cooling is slowly effected this homogeneity is disturbed, the external portions being slightly richer in silver than the centre. Fig. 5 exhibits the results of an experiment on the alloy which has the lowest melting-point and the simple chemical formula $AgCu$. Its structure is interesting, as the action of gravity appears to have influenced the arrangement, the lower parts of the cube being richer than the upper. The maximum difference is 21·1 parts per thousand. I should observe that Levol found the corners of a cube of this alloy to be 15 parts richer than the centre; but the only alloy in which he detected any effect of gravity was that containing 690 parts of silver. Fig. 6 shows the results of analyses on the different portions of a mass of the alloy containing 333·3 parts of silver per thousand ($Ag\,Cu_4$). The mass varies in composition, but the arrangement does not appear to have been guided by any law.

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* In treating of ingots of low standard, Jars stated in 1781, in the work to which I have already alluded (note, p. 481):—"Je remarquai par des expériences que pour rendre les lingots d'une teneur plus égale dans toutes les parties il falloit que les lingotières fussent aussi chaudes qu'il est possible." I should state that certain unpublished experiments by Dr. Boycott, formerly Assay Master in the Calcutta Mint, have shown that the liquation of silver-copper alloys is modified by casting the metal in sand moulds, and that Mr. E. Seyd suggested in 1871, in a work printed for private circulation, the use of hot iron moulds in casting gold and silver, as an improvement in the process of coinage, the bars being "more equal in temper and in molecular arrangement" (patented in 1872, No. 368).

The inquiry appears to show that several alloys of silver and copper are, under suitable conditions, as homogeneous as Levol's alloy, the chief peculiarity of which consists in its not being liable to liquation when poured into a mould at the ordinary temperature and cooled rapidly.

It will be remembered that experiments prove that in all alloys which contain less than 71·89 per cent. of silver the external parts are richer than the centre. The curve of fusibility shows that the alloys which contain less than 35 per cent. of silver have higher melting-points than other alloys of silver and copper, or even than pure silver. It would not appear, therefore, that liquation is the falling out of the least fusible alloy present in a mass of silver and copper; for if it were, the external portions of the alloys would in all cases be less rich in silver than the centre.

I cannot at this stage of the inquiry offer a complete explanation of this molecular rearrangement; but I venture to think that the results already obtained are interesting. They show, first, that the same alloys are situated on the turning-points of the curves of fusibility and electric conductivity; and second, that the arrangement of an alloy is to a great extent dependent on the rate at which it is cooled.

In accordance with a suggestion made to me by Mr. R. Mallet, I have endeavoured to determine the relation between the densities of silver in the solid and the molten state. I adopted the method which he devised and has employed in the determination of the density of molten cast iron *.

A conical vessel of best thin Low-Moor plate (1 millim. thick), about 16 centims. in height, and having an internal volume of about 540 cub. centims., was weighed, first empty, and subsequently when filled with distilled water at a known temperature. The necessary data were thus afforded for accurately determining its capacity at the temperature of the air. Molten silver was then poured into it, the temperature at the time of pouring being ascertained by the calorimetric method already described. The precautions, as regards filling, pointed out by Mr. Mallet were adopted; and as soon as the metal was quite cold, the cone with its contents was again weighed.

The surface of the molten metal in the crucible was covered with charcoal; and as pure silver, when in a liquid state, is known to absorb oxygen if exposed to the air, the cone was filled with an atmosphere of coal-gas.

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* Proc. Roy. Soc. vol. xxii. p. 366, and vol. xxiii. p. 209.

The most important of the corrections applied to these results was that for change of volume of the iron vessel which attended the introduction of the molten metal.

Different qualities of wrought iron vary considerably as to dilatation by heat. This fact, together with the known increase in the expansion at high temperatures, rendered it necessary to determine the mean coefficient between 0° C. and the melting-point of silver. For this purpose a modification of Ramsden's method was adopted, the iron being placed in a graphite trough and surrounded by molten silver. The micrometer-reading was taken when the length of the iron remained for a short period invariable, as this was the true solidifying-point of the silver, the loss of the latent heat of liquefaction rendering the temperature constant.

A great number of experiments were made; and although they were attended with much difficulty, I believe the following results to be trustworthy (the numbers represent the mean coefficient of linear expansion per 1° C. of the Low-Moor iron employed, up to the temperature of melting silver):—

·00001242,
·00001254,
·00001215,
·00001219,
·00001271,
Mean.... ·00001240,

which gives a mean coefficient of cubical expansion

·00003720.

This result is considerably higher than that of Rinmann, who gives 0·00002808 as the mean coefficient of cubical expansion of wrought iron between 15° C. and "a white or welding heat."

The results of the experiments made with a view to ascertain the densities of pure silver and of Levol's homogeneous alloy when in a molten state are given in the accompanying Table (p. 495). This alloy was chosen for the experiment, as its density when solid very nearly agrees with that calculated from the densities of the constituent metals.

The cubic dilatation was, in the case of pure silver, in the ratio of 9·4612 : 10·57. Deducing from this the mean coefficient through, say, 1050° C., we obtain

0·00011164 per 1° C.

The coefficient of linear expansion was therefore

0·00003721.

The mean of the coefficients of linear dilatation of silver between 0° and 100° C., given by various authorities, is

$$0{\cdot}00002015.$$

It will thus be seen that the expansion of silver between 0° C. and 1050° C. is about twice as much as it would have been had this rate of expansion been maintained through the whole range of temperature.

The mean coefficient of linear dilatation of Levol's alloy, as deduced from the results given in the Table, is

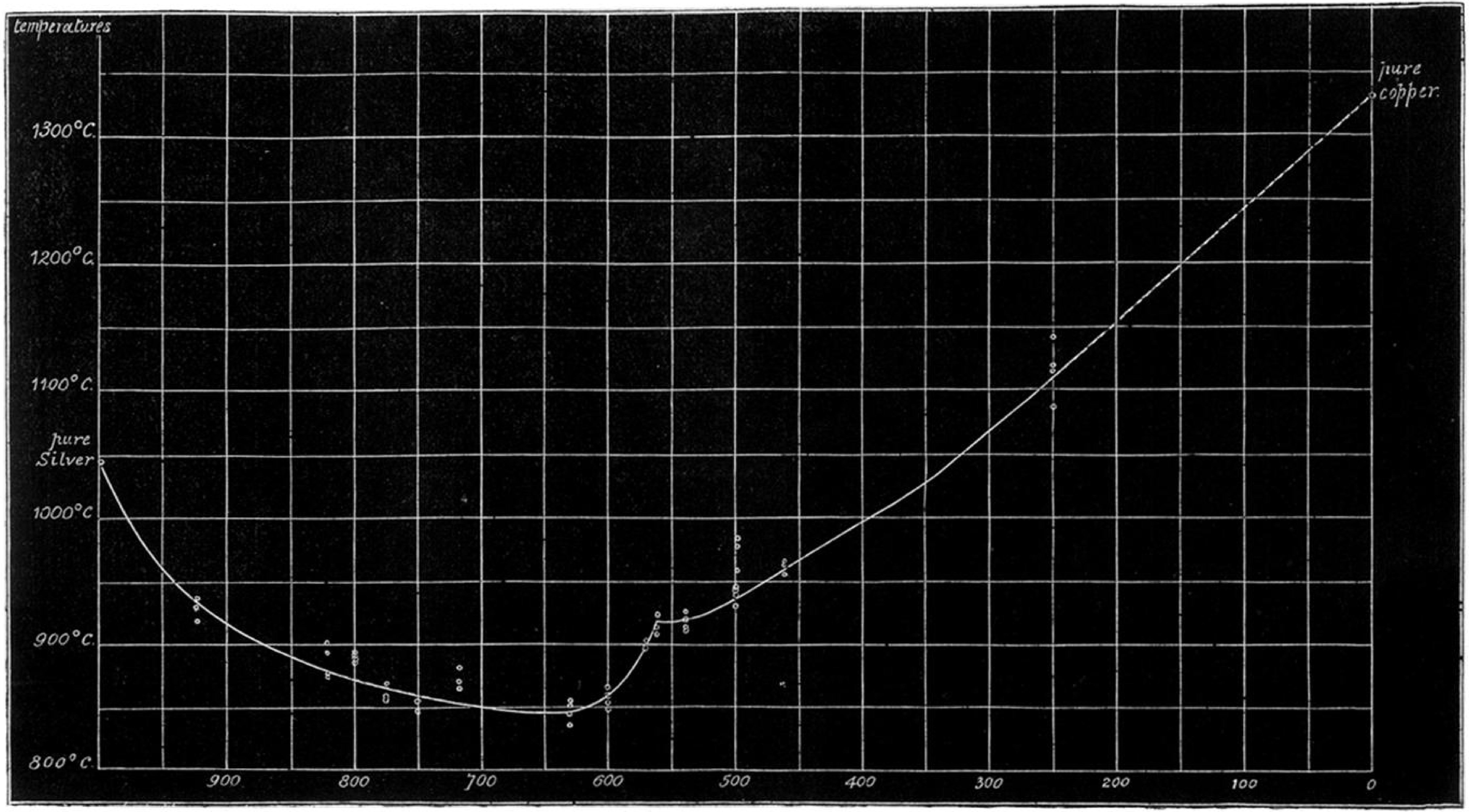
$$0{\cdot}00003703\,;$$

but it is impossible to compare this with the rate of expansion at low temperatures, as the latter has not been ascertained.

	Initial volume of cone.	Volume of cone filled with molten metal.	Temperature of metal when poured.	Weight of metal.	Density when fluid.	Density of solid metal.
	c. c.	c. c.	°C.	grms.		
Pure silver.	536·6	556·3	1143	5255·4	9·4468	10·57
	542·9	564·4	1223	5348·3	9·4757	
	Mean				9·4612	
Levol's alloy.	735·13	778·06	1020	7062·4	9·0788	9·9045 [Levol], 9·998 by calculation.
	537·42	557·25	1131	5033·4	9·0321	
	Mean				9·0554	

In conclusion I have much pleasure in acknowledging the assistance I have received from one of the Assistant Assayers, Mr. Edward Rigg, whose cooperation has been of much service to me; and I must also express my thanks to Joseph Groves, Senior Fireman, who aided me in the furnace-operations.

MELTING-POINTS OF SILVER-COPPER ALLOYS.



Parts of Silver in 1000 parts of Alloy.

ALLOY CONTAINING { 925 SILVER. 75 COPPER.

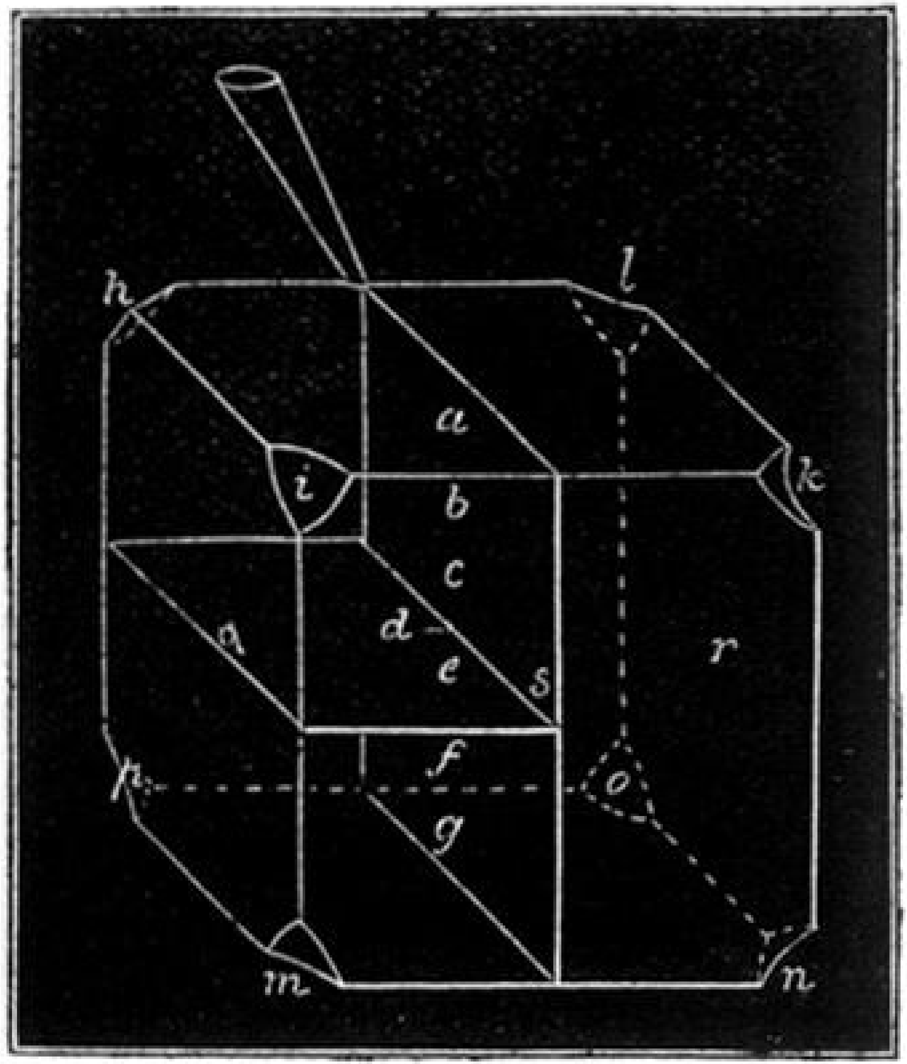


Fig. 1.

RAPIDLY COOLED.

Vertical Plane.	*a.*	924·6
	b.	926·0
	c.	929·1
	d.	935·5
	e.	931·0
	f.	925·0
	g.	924·2
Corners.	*h.*	923·2
	i.	923·7
	k.	923·3
	l.	923·3
Corners.	*m.*	923·9
	n.	923·8
	o.	922·7
	p.	923·2
Sides.	*q.*	923·6
	r.	923·8
	s.	923·1

"Dip assay," 925·1.

Maximum difference [between the centre and the corners], 12·8 per thousand.

ALLOY CONTAINING { 900 SILVER.
100 COPPER.

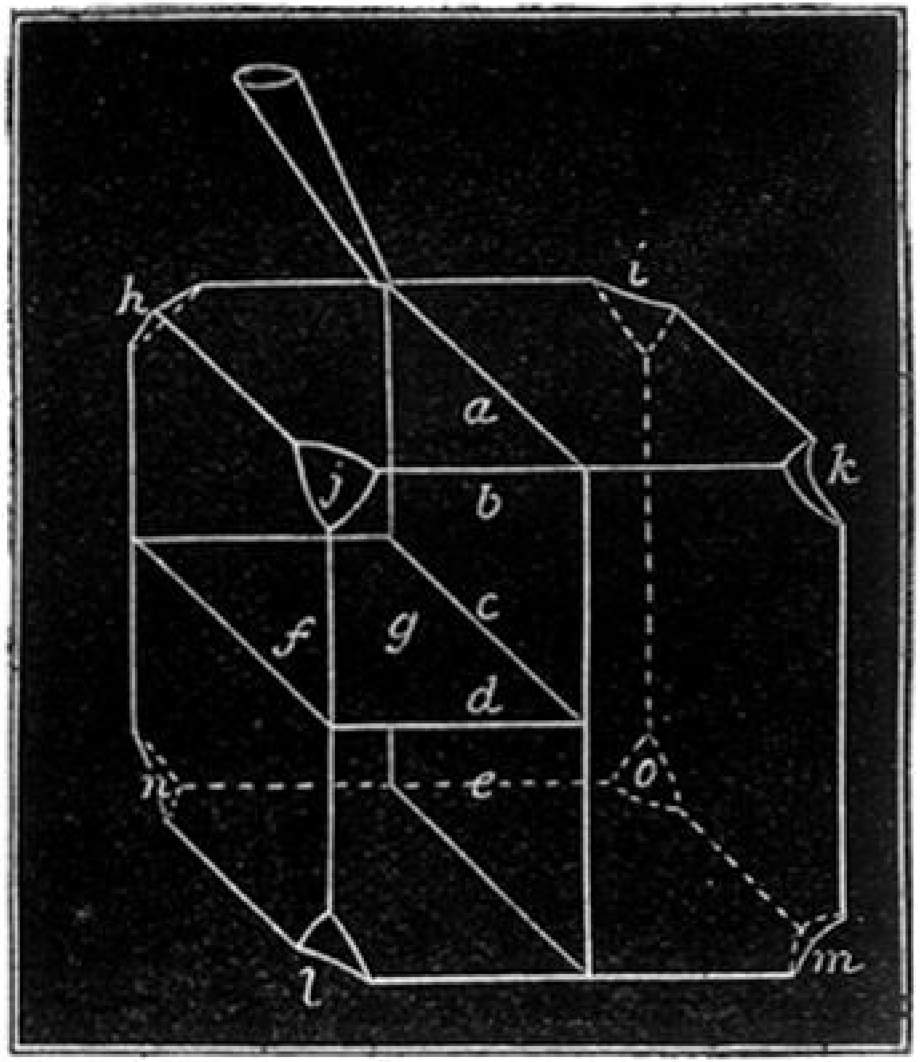


Fig. 3

SLOWLY COOLED.

Vertical Plane.	*a.*	899·0
	b.	899·2
	c.	899·6
	d.	898·6
	e.	899·1
Corners.	*h.*	898·9
	i.	898·6
	j.	899·4
	k.	898·3
Corners.	*l.*	899·6
	m.	899·5
	n.	899·3
	o.	898·8
Horizontal Plane.	*f.*	898·5
	g.	898·6

"Dip assay," 900·4.

Maximum difference, 1·3 per thousand.

ALLOY CONTAINING {630·3 SILVER.
369·7 COPPER.}

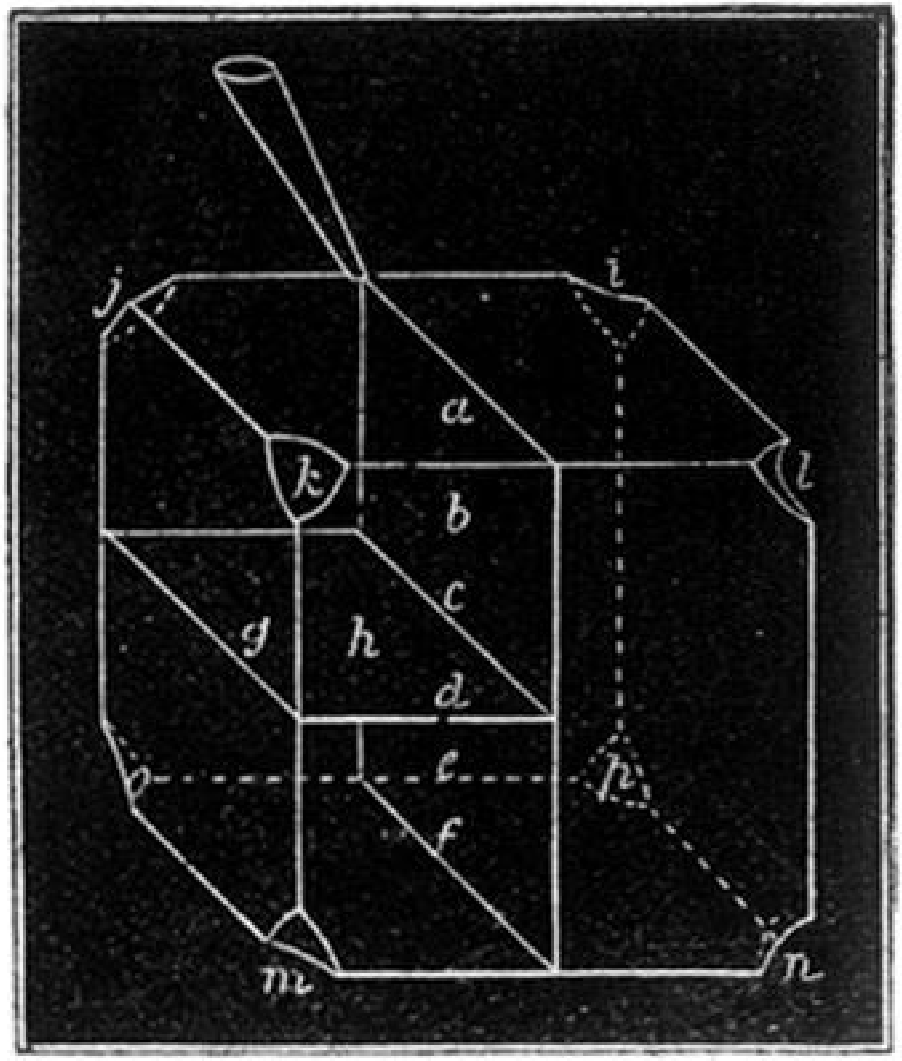


Fig. 5

SLOWLY COOLED.

Vertical Plane.	*a.*	614·9
	b.	631·5
	c.	636·0
	d.	635·0
	e.	630·9
	f.	634·8
Corners.	*i.*	620·6
	j.	620·3
	k.	625·9
	l.	625·0
Corners.	*m.*	632·6
	n.	633·5
	o.	633·9
	p.	634·
Horizontal Plane.	*g.*	631·4
	h.	635·9

"Dip assay," 630·2.

ALLOY CONTAINING { 925 SILVER.
75 COPPER.

SLOWLY COOLED.

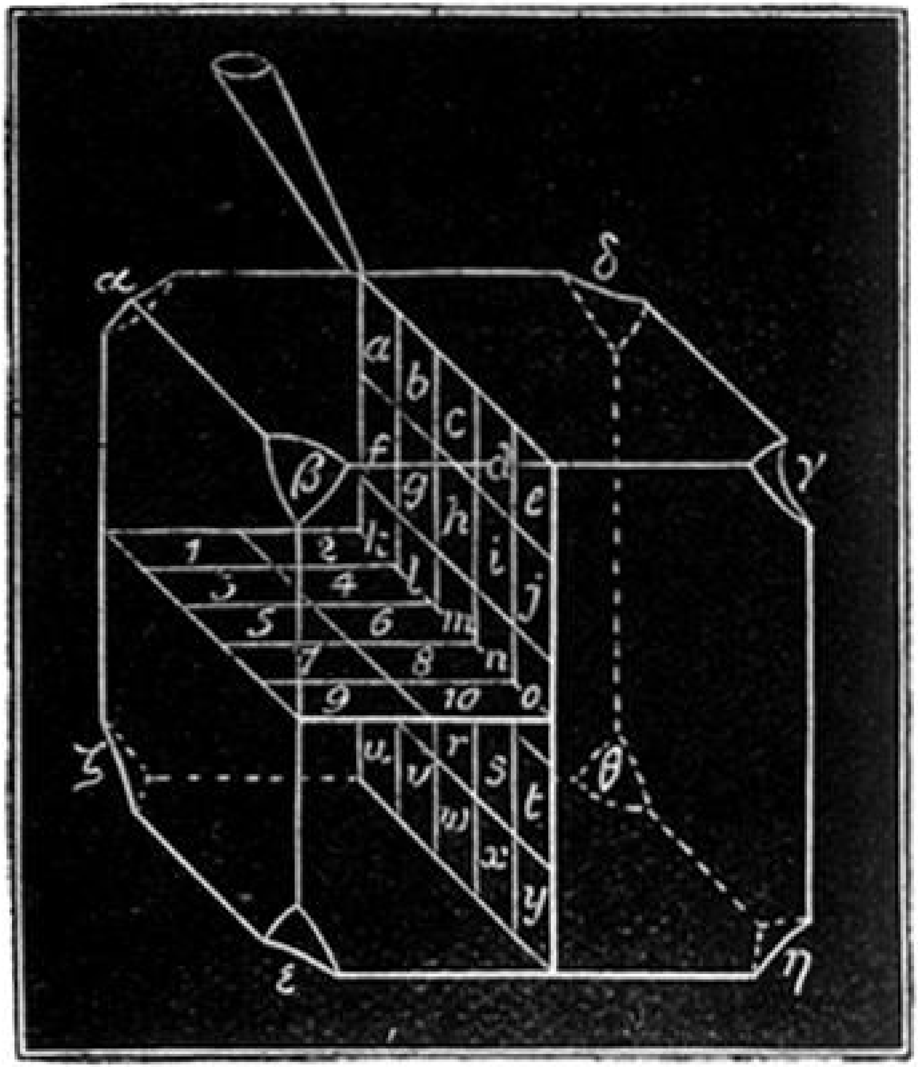


Fig. 2.

Vertical Plane.	
a.	925·7
b.	925·0
c.	925·0
d.	925·0
e.	925·4
f.	924·3
g.	925·0
h.	925·3
i.	925·3
j.	925·3
k.	924·3
l.	925·3
m.	925·3
n.	924·4
o.	925·0
p.	924·3
q.	925·0
r.	925·3
s.	925·0
t.	924·9
u.	924·3
v.	924·7
w.	924·9
x.	924·9
y.	925·3

Horizontal Plane.	
1.	924·8
2.	925·0
3.	924·9
4.	924·9
5.	925·0
6.	925·1
7.	925·1
8.	925·1
9.	925·0
10.	925·0

Corners.	
α.	924·1
β.	924·1
γ.	924·1
δ.	924·4
ε.	924·0
ζ.	924·2
η.	924·2
θ.	923·9

"Dip assay," 924·9.

Maximum difference [between the centre and the corners], 1·40 per thousand.

ALLOY CONTAINING { 718·93 SILVER.
281·07 COPPER.

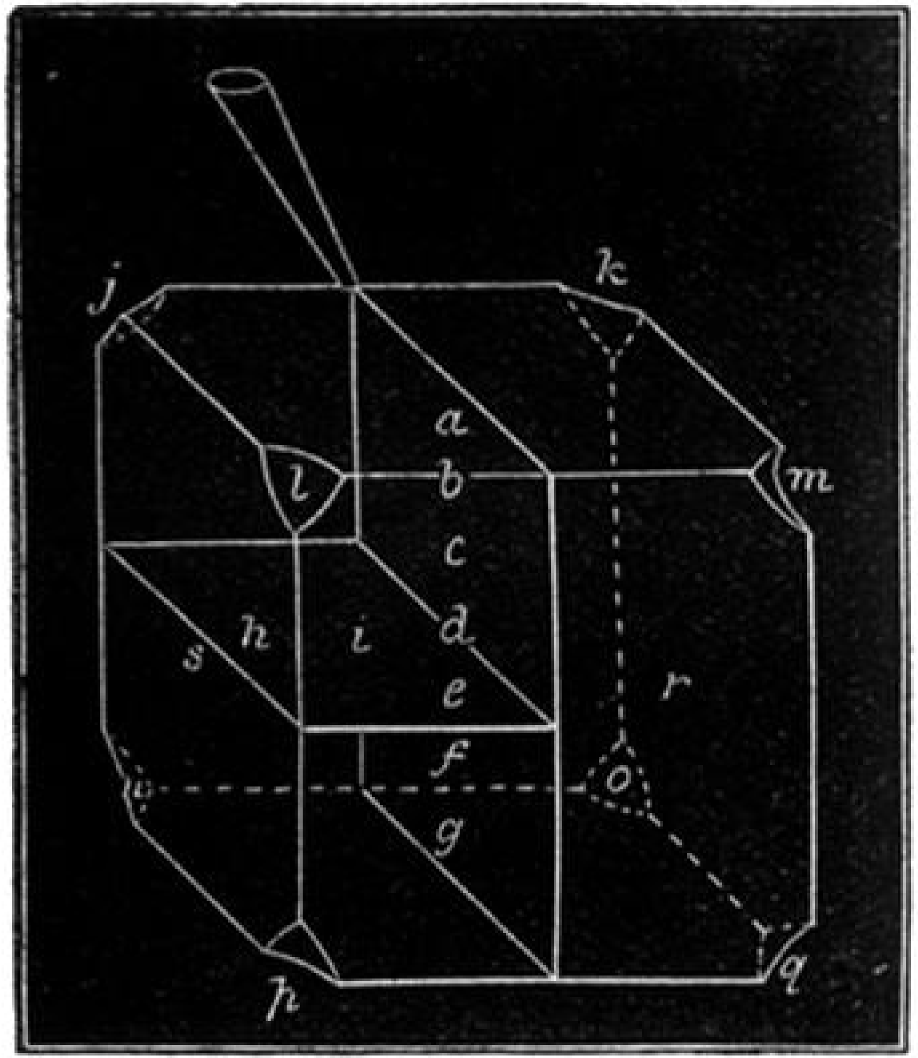


Fig. 4.

SLOWLY COOLED.

Vertical Plane.		
	a.	718·3
	b.	719·5
	c.	718·3
	d.	718·4
	e.	718·3
	f.	718·4
	g.	718·2

Horizontal Plane.		
	h.	718·7
	i.	718·5

Corners.		
	j.	719·0
	k.	719·0
	l.	719·0
	m.	719·4
	n.	719·1
	o.	719·0
	p.	719·0
	q.	719·1

Sides.		
	r.	718·8
	s.	718·4

"Dip assay," 719·0.

Maximum difference, 1·2 per thousand.

ALLOY CONTAINING { 333·3 SILVER.
666·7 COPPER.

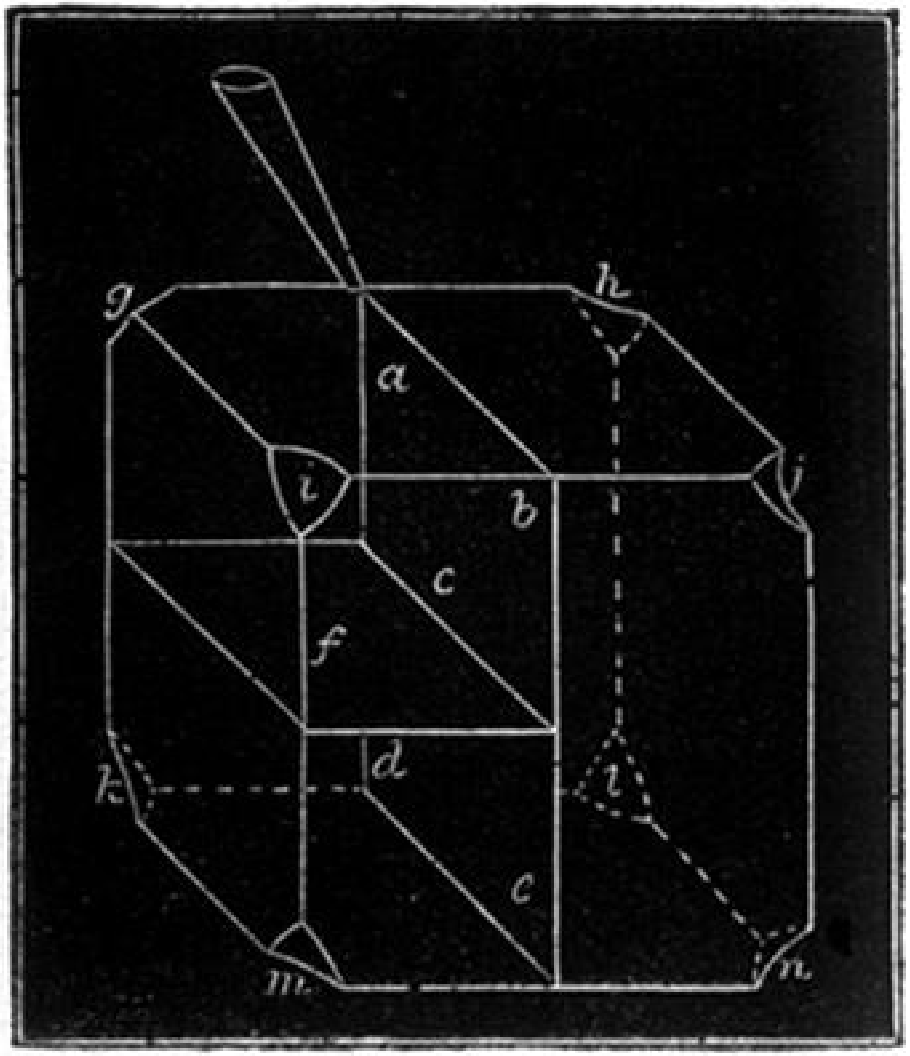


Fig. 6.

SLOWLY COOLED.

Vertical Plane.	
a.	342·8
b.	333·0
c.	337·5
d.	330·0
e.	332·0

Corners.	
k.	331·0
l.	334·0
m.	336·3
n.	334·4

Corners.	
g.	331·0
h.	332·0
i.	331·5
j.	334·8

Horizontal Plane.	
f.	336·2

"Dip assay," 333·4.

Fig. 7.